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FAULT COASTS IN NEW ZEALAND

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INTRODUCTION

The scientific study of scenery has engaged the interest of geographers ever since the time that explanation began to supplement mere description. There is an infinite variety of landscapes, and among them are types that make their sentimental or intellectual appeal to this class or to that. The stern shores of the fiorded Alaskan coast and the bitter walls of rock that meet the Atlantic in western Scotland are a challenge to the imagination of even primitive men. To the philosophic student of modern times they appeal to the investigating sense no less than to the emotions. The finer shades of appreciation find an ample field in the delicate beauty of terraced coasts or the tree-fringed islets of tropical seas. Yet here, as on the bolder coasts of the world, man's sense of how and why is stirred to action. Thus there has arisen a phase of physiography that deals with the shore, with its multiplicity of forces, and its infinite and inspiring detail.

The topography of continental interiors represents chiefly the reaction between air and water on the one hand and the crust of the earth on the other. The topography of the shore is vastly more complex. A third agent, the sea, plays its varied rôle upon a surface already complicated by subaërial agents. When to this diversifying agent there is added crustal fracturing of unlike kind in unlike amounts, and all the irregularities of form produced by crustal warping, the result is likely to be a problem of the first rank. Moreover, the shore-line runs its cycle of change in obedience to laws and at a rate wholly unlike those that affect the interior of the land. At any stage in the normal cycle of the land the sea-shore may have reached a wholly different stage in its development. In the inharmonious relations of these forces lie half the physiographic problems of the coast.

To put into an orderly scheme so complex a set of agents and forms as the coast lines of the earth display, the great masters, Suess and Richthofen, each attempted to classify the various coastal forms by groups, and each believed that he recognized a group in which crustal fractures determined the position of the shore-lines. Thus we have the "Atlantic" coasts of Suess and the *Beckenrandküsten* of Richthofen. Suess defines the Atlantic type as follows: "The inner sides of folded ranges, jagged rias coasts which indicate the subsidence of mountain chains, fractured margins of horsts-

and fractured table-land form the diversified boundary of the Atlantic Ocean.''[1] Richthofen's *Beckenrandküsten* are formed by the walls of basins due to foundering on the inner side of mountain ranges. It is interesting to note that Richthofen regarded the east coast of New Zealand as of this type and considered it exceptional in that it faced the open ocean.[2]

These classifications of coast type are based upon the broad structural features of the adjacent lands. In framing them their authors, particularly Suess, paid little attention to the actual features of shore-lines, to the topographic forms of coastal lands, or to the configuration of neighboring sea floors, any or all of which may throw light on the origin of a coast.

In a recent European classification of coasts, that of De Martonne, we find *côtes des régions d'effondrement* with initial forms determined entirely by fractures. As examples are cited the coasts of Greece, southern Italy, and Japan.[3]

Turning next, however, to the writings of geomorphologists of the American school, we find that fault coasts are not recognized by them. Gulliver[4], for example, has distinguished as initial forms of shore-lines those resulting from ''uniform uplift,'' ''uniform depression,'' and ''diverse movements,'' and among the last he has mentioned ''crumpling and faulting''; but, in the study of sequential forms, he has not recognized any features as characteristic of shore-lines the initial forms of which were fault scarps. The omission was, no doubt, due to the circumstance that, in the material available for study, coasts that had previously been regarded as fault coasts, e. g., some of the Atlantic coasts of Suess, found a more acceptable explanation as sequential forms developed from initially depressed, uplifted, warped, or tilted coasts.

The writer therefore deems it advisable to sketch briefly a scheme of forms which fault coasts may be expected to exhibit, before setting out his reasons for believing that certain of the coasts of New Zealand are of this kind. A complete scheme would be too long for presentation, and so only such portions of a complete scheme will be given as seem applicable to those coasts which the writer has had the opportunity of examining.

The Fault-Coast Hypothesis

INITIAL FORMS

The essential feature of a fault coast is a fault scarp separating a higher-standing earth-block, which, after faulting, forms the land, from a lower-lying block, which, after faulting, is depressed below sea-level. The pre-faulting surface may have any form. It may be a level sea-floor, or it may be a land surface with low, moderate, or strong relief. The vertical displacement on the fault may be small or great if the pre-faulting surface has low relief, but, if the pre-faulting surface has strong relief, a continuous fault coast can be formed only by a vertical movement of hundreds, perhaps thousands, of feet; that is to say, the movement must be sufficient to submerge the ridges of the down-thrown block. Incomplete submergence would result in the formation of outlying islands, peninsulas, and promontories, as partially drowned ridges would project seaward from the fault line (Fig. 1).

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[1] E. Suess: The Face of the Earth (Engl. transl.), Vol. 2, Oxford, 1906, p. 203.

[2] F. von Richthofen: Führer für Forschungsreisende, Hanover, 1886, p. 300.

[3] E. de Martonne: Traité de Géographie physique, 2d edit., Paris, 1913, p. 712.

[4] F. P. Gulliver: Shoreline Topography, *Proc. Amer. Acad. Arts and Sci.*, Vol. 34, 1899, pp. 151-258.

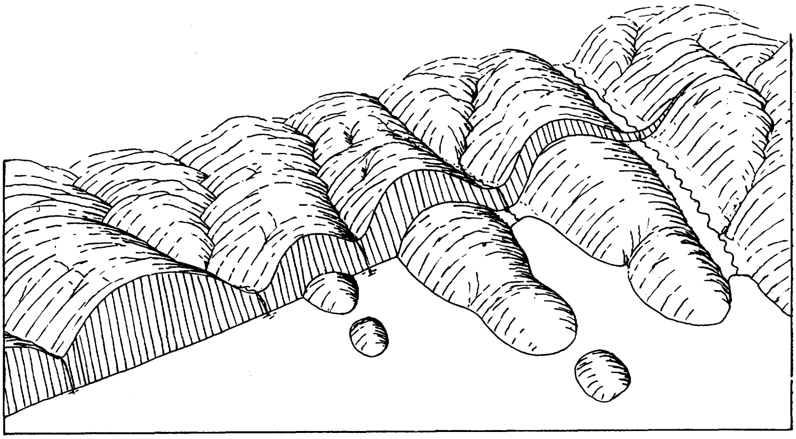

FIG. 1—A fault coast (on the left) formed by a fault scarp diminishing in height towards the right, where islands and promontories make their appearance seaward of the scarp and the fault dies out inland.

The movement of the earth-block is relative movement, and so various cases arise, according as the landward block has been uplifted, has remained stationary, or, if the region was formerly above sea-level, has subsided with, though to a smaller extent than, the seaward block. It is thus possible to imagine many variants of the initial form. A transition may be traced, for example, from a normal fault coast through a case in which the pre-faulting surface has no relief, with diminishing and finally vanishing displacement on the fault, to a normal uplifted coast (Fig. 2).

A transition in the other direction may be traced through a case in which the pre-faulting surface is an accidented land surface, with increasing depression of the landward block, to a normal depressed coast (Fig. 3).

In order to simplify this discussion, attention may be directed principally to those cases in which the pre-faulting surface is a land surface of moderate to strong relief, in which the seaward block is completely submerged, and in which the displacement on the fault is considerable. Imagined initial fault coasts, thus limited, fall into two groups. The first includes those during the formation of which the landward block rises or remains stationary (Fig. 4, block *A*). In either of these cases the shore will be formed by a continuous fault scarp differing from the initial form of a fault scarp on a land surface in no respect except that the base of the visible portion will be the horizontal sea-margin. All along the coast betrunked streams will cascade into the sea from the mouths of hanging valleys. Fault coasts of a second kind may be formed if a movement of subsidence in the landward block accompanies faulting (Fig. 4, block *B*).

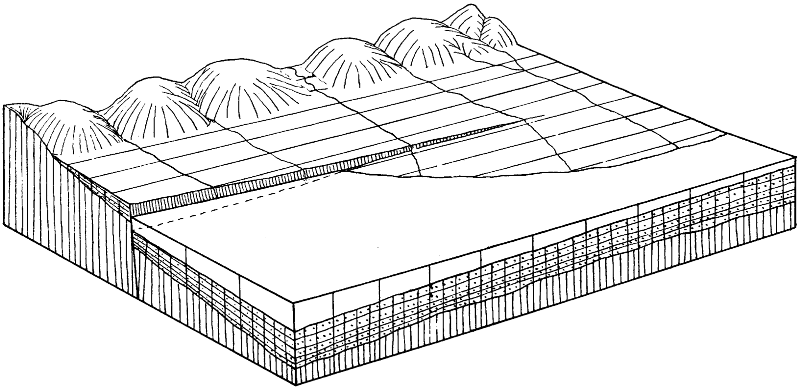

FIG. 2—A fault coast, on the left, formed by a fault scarp diminishing in height and dying out towards the right, where the coast passes into a normal uplifted coast.

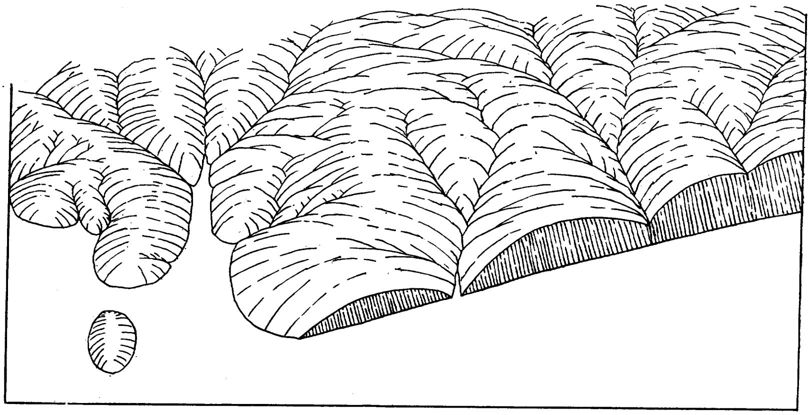

FIG. 3—On the right a fault coast, which, owing to downward tilting of the landward block toward the left, passes into a normal depressed coast on the left.

If the subsidence is sufficiently great, the deeper valleys of the pre-faulting surface will be drowned and the initial shore-line will therefore be less simple than in the preceding case, as there will be a few reëntrants breaking the simple line of the fault coast. In order to simplify the discussion as far as possible, it is assumed that the seaward block sinks to such a depth that the underwater portion of the fault scarp forming the initial coast descends everywhere into deep water (to a depth of 600 feet or more). Seaward, the sea-floor will have, initially, the relief of the submerged land surface, while, close inshore, the initial floor will slope steeply seaward, being formed by the fault scarp itself if the fault hades seaward at a considerable angle, or, if the fault is nearly vertical or overhangs, by a talus of waste that has broken away from the crest of the landward block while the faulting movement was in progress. (For convenience it is assumed that the work of erosion is not begun until the earth movements that produce the initial form are at an end. In nature erosion is never thus delayed, but the writer believes that the sequential forms of fault coasts may be most satisfactorily deduced with this assumption and that the errors resulting from it are very slight.)

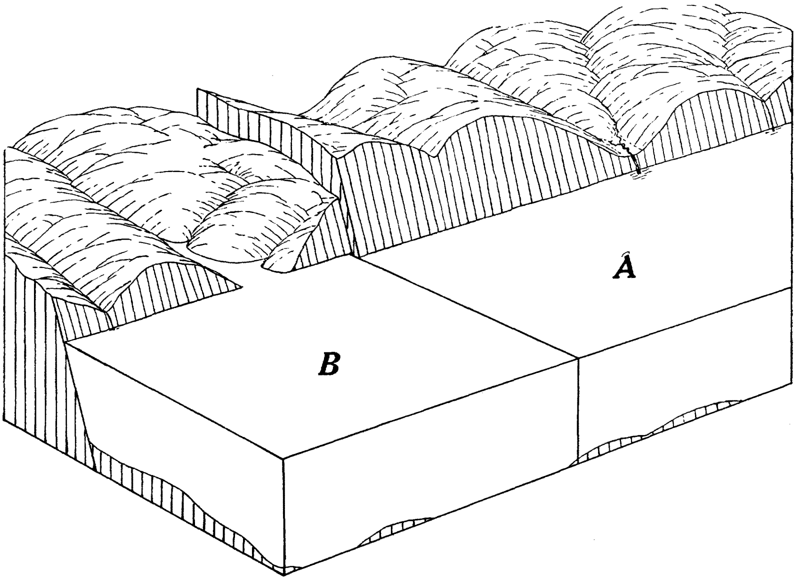

FIG. 4—Two initial fault coasts. In block *A* the landward block has risen or has remained stationary, while in block *B* it is slightly depressed. The seaward block is depressed to the same extent in *A* and *B*.

SEQUENTIAL FORMS WITH STATIONARY SEA-LEVEL

The Landward Block: Rejuvenation. In the case under consideration, where the pre-faulting surface is a land surface, it is to be expected that some of the valleys transected by the fault will drain inland and others seaward. The streams which flow seaward across the newly formed fault scarp, and at first cascade from hanging valleys, will begin at once to cut notches at their mouths. The larger of these streams will rapidly develop new, young valleys—steep-sided ravines at first—within the more mature valleys of the pre-faulting surface. Naturally the contrast of the post-faulting with the pre-faulting features will be most marked, and the merging of the former with the latter will be longest delayed when the pre-faulting surface is well advanced in the cycle of erosion and reduced to moderate or low relief. The heads of the young ravines of the revived streams will advance headward up the older valleys, and so, early in the history of the fault coast, the region will be characterized by composite topography. At the mouths of the minor seaward-sloping hanging valleys, however, notch-cutting will be slow, on account of the feebleness of the streams, and so the valleys of many small streams will long remain hanging.

In the case of transected valleys the slope of which is towards the landward block there will be, obviously, no tendency towards deepening by stream action, any deepening that was formerly in progress having been brought to an end when the streams lost their headwaters, that is to say, when they were beheaded by faulting. Such streams will now be misfits—too small for their valleys. Not possessing the power of rapid down-cutting, they, as rejuvenation of the topography progresses, will be liable to be captured by the vigorous tributaries of those revived streams, previously mentioned, which now flow down steep gradients to the sea in their newly deepened valleys. Thus it may happen that, if a coast has been formed by faulting and sufficient time has since elapsed to allow of adjustment of streams to the new conditions, some rivers will rise near the sea, flow inland for some distance and then, after turning sharply around to right or left, flow to the sea along courses more or less parallel with their headwaters. Somewhat similar conditions would result from the rapid consumption of a land area by marine erosion, but, since such rapid consumption of the land can take place only as an accompaniment of subsidence[5], in that case the stimulus to capture afforded by the rejuvenation of large neighboring streams would be absent, or, if not quite absent, at least much less effective. The presence of stream courses of this kind may be taken not as definite proof but as presumptive evidence that the land on which they occur is bounded by a fault coast. Their absence, on the other hand, does not disprove faulting, as streams flowing inland on the initial surface of the landward block may be infrequent or altogether absent. This will be the case when a coast has been formed by faulting not far inland from the former coast.

The Landward Block: Result of Depression. The changes in the topography thus far described are of the same nature as those that will take place on the surface of a block mountain in the neighborhood of the fault scarp that separates it from the adjacent lower-lying block, in that case unsubmerged. It makes no essential difference whether the block mountain has, in the process of faulting, been itself uplifted, has remained stationary, or has been depressed, provided only that it is relatively higher than the adjacent block, for, in all cases, the local base levels for streams on the pre-faulting surface of the mountain block are lowered throughout the length of the fault scarp.

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[5] A. C. Ramsay: Physical Geology and Geography of Great Britain, 5th edit., London, 1878, p. 497; F. von Richthofen: Führer für Forschungsreisende, Hanover, 1886, pp. 354-355.

In the case of the land bordering a fault coast, however, this is not so in every case. It has been pointed out above that the initial form of the shoreline with the landward block depressed will show, in some cases, reëntrants formed by the drowning of portions of valleys. At all points along the shores of these reëntrants local base levels are not only not lowered, but are replaced by permanent base level, the shore line within a reëntrant being simply that of a short length of depressed coast.

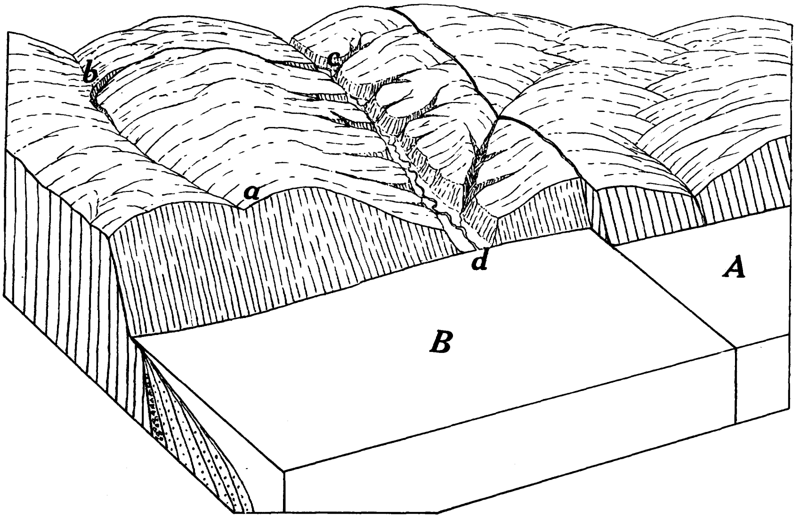

Fig. 5—Early sequential form, block *B*, developed from an initial fault coast, block *A*. In block *B* the inland-flowing stream *ab*, already beheaded by faulting, has been captured by a tributary *bc* of the revived seaward-flowing stream *cd*.

Along stretches of the coast scarp all the betrunked valleys will be initially hanging, but such will be only those of the smaller seaward-flowing streams, and consequently their lips will be but slowly notched. While valley-in-valley forms will be produced to some slight extent near the sea, general rejuvenation of the topography will not take place as in the case previously considered, and readjustments of stream courses by capture are not to be expected.

The larger valleys, which are drowned at their mouths, will be affected by bay-filling, delta-building, and up-valley aggradation; and those exceptional valleys that have accidentally been cut across by the fault just at sea-level will be unaffected until caused to degrade by retrogradation of the shore.

With increasing depression of the landward block we have the transition to a normal depressed coast previously referred to (Fig. 3); as the sea advances over the coastal land the fault scarp passes too far seaward to be of any further significance as a coast feature.

Shore Features in Profile. Scarps of the kind considered in this discussion are cut through here and there, at a very early stage in their history, by revived, outward-flowing streams; and, even if such streams are absent, the continuity of any fault scarp must soon be destroyed as a result of the excavation of ravines by new, consequent streams. It has been shown, however, by Davis[6] that, in the case of a fault scarp descending to a land surface, facets, triangular remnants preserving the form of the initial fault scarp, are to be found on spur ends even when dissection of the mountain block is far advanced. Such facets are subject to constant reduction in size as the spurs which they truncate are reduced in width and height by the widening of the valleys on either side, but the flat surface of a facet, though slowly wasted by soil creep, will be subject to little change of form beyond a certain amount of reduction of steepness and loss of sharpness of the edges. While any facets of such a scarp remain they can have retreated but little from the fault line, and they will therefore retain their alignment[7].

In the case of a fault scarp descending to the sea—an initial fault coast—, on the other hand, the scarp is attacked by wave action and will be worn back from the fault line. When the coastal land has been dissected by streams, the intervening spurs will end in facets or cliffs, but these will be true wave-cut cliffs and not remnants of the original scarp. It is true that, in the case we are considering, where the initial scarp descends with a steep slope into deep water, wave action must at first be feeble, as Fenneman[8] has pointed out, on account of the reflection of waves from the steep shore, and also on account of the absence of a resting place for loose material at a convenient depth to allow it to be picked up and made use of by waves in their attack on the face of the cliff. Such material as is dislodged by the impact of waves on the initial shore will slip immediately into deep water. When, however, the scarp, if initially too steep to cause waves to break, has had its steepness reduced by slumping and by slower surface creep, accompanied by accumulation of talus at the base of the slope (Fig. 6, *b* and *b′*), waves will break and, by their impact, will dislodge weathered material and joint-bounded blocks. Thus a nip will be developed (Fig. 6, *c*), slowly at first if there is still a lack of "tools", as in Figure 6, *b*,

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[6] W. M. Davis: The Mountain Ranges of the Great Basin, in Geographical Essays, Boston, 1909, pp. 725–772 (first published in *Bull. Mus. Compar. Zool. Harv. Coll.*, Vol. 42, 1903).

[7] *Ibid.*, p. 747.

[8] N. M. Fenneman: On the Lakes of Southeastern Wisconsin, *Wis. Geol. and Nat. Hist. Surv. Bull. 8*, 1902, p. 23.

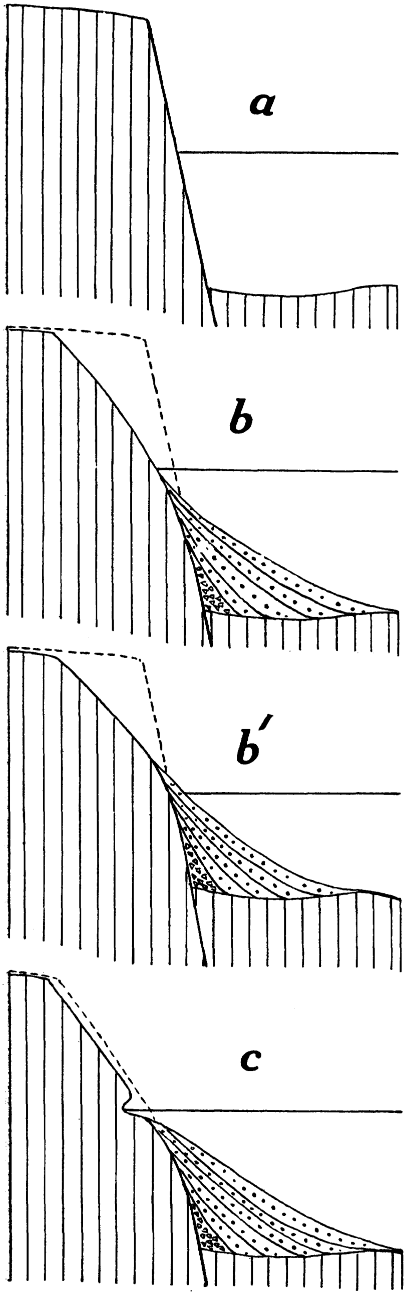

FIG. 6—To illustrate the beginning of wave attack on a steep coast. *a*, initial form; *b*, *b′*, *c*, sequential forms.

with which the waves can exert a truly abrasive action, but more rapidly if, as in Figure 6, *b′*, the material of the talus supplies tools[9]. The action will go on with increasing rapidity as the increasing width of the rock bench allows of the lodgment of coarse waste, insuring a supply of the material which most effectively assists waves to abrade solid rock.

After this stage is reached the conditions will be for a time those which allow wave action to work with maximum efficiency as a destructive agency. Deep water will still be present at a short distance from the shore, and so the waves will reach the rock bench on which they break with their energy unimpaired by friction of the bottom. Most of the finer and much of the coarser products of abrasion, moreover, will be withdrawn immediately from the arena, as they sink or slide to the bottom at a depth below strong wave action, if not quite below wave base. There will thus be no clogging of the shore with waste: bare rock will be exposed nearly continuously over the rock bench and at the base of the newly cut cliff, and this bare surface will be constantly exposed to abrasion during storms by that portion of the coarse waste which remains on it.

At the same time, the initial floor being assumed to be below strong wave action, deposition will go on extremely rapidly near shore, so that, very early in the history of the fault coast, the slope of the rock shelf or cut platform will be continued seaward by a built platform or "continental delta" (Gulliver). Thus a continental shelf will come into existence along the faulted margin of the land.

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[9] N. M. Fenneman: *op. cit.*, p. 23.

Though, at this stage, the combined cut and built platform will still be narrow, and though the slope to its outer edge, which will be situated at the depth of wave base, will still be somewhat steep, the underwater profile will now have attained the form described by Davis as "grade"[10] and by Fenneman as the "profile of equilibrium."[11] While the seaward slope of the platform, as it grows in width, will afterwards become progressively less steep, and the depth of water at any particular point on the landward portion of it will continue to increase,[12] the profile will remain graded throughout the cycle.

Provided that complete exportation of the waste to be deposited at another part of the coast-line does not take place as a result of currents sweeping along the stirred sediment above the wave base, a constant stream of material will, at this stage, be carried seaward over the edge of the platform to rest in layers upon and with the inclination of the continental slope. Such inclined layers are, as Chamberlin points out, foreset beds analogous with the foreset beds of a delta.[13] The platform will thus, normally, grow rapidly seaward; and the width of the built platform will soon be much in excess of that of the cut platform, this excess depending mainly (in the absence of loss of waste to, or gain from, other parts of the coast as a result of transportation by currents) upon the amount of waste supplied by streams as distinct from that broken by wave action.

Shore Features in Plan. While, as pointed out above, destruction of the initial scarp is likely to be at first somewhat delayed, after wave action has become effective the shore-line will retreat rapidly; and this will be evidenced by the failure of dissecting ravines to attain or maintain grade, especially in the more resistant rocks. In plan, one of the first effects will be that the shore-line will assume minor irregularities as marine erosion picks out the variations of resistance inevitably present in the shore rocks from point to point. A later effect will be the development of broad reëntrants where large areas of weak rocks reach the sea or where for any reason the initial scarp is low. At low parts of the scarp there is a smaller quantity of talus slipping down upon the shore as the base of the cliff is cut back, and, as the talus thus originating prevents further undercutting and so delays the work of marine erosion until it is itself transported seaward by the waves, it is clear that where the cliffs are low the shore-line will retreat rapidly, and that those portions of the shore-line where the cliffs are high will soon project somewhat as broad salients beyond the general line. Since, if we continue to assume that in the pre-faulting cycle of subaërial erosion planation was incomplete, the areas of weaker rocks will in that cycle have been reduced to lower relief than the resistant rock areas, it is apparent that broad differences of rock strength will be effective in two ways in producing sinuosity of the shore-line: first on account of the smaller resistance to erosion offered by the weaker rocks, and secondly on account of the smaller height of the initial scarp on these rocks (Fig. 7).

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[10] W. M. Davis: The Outline of Cape Cod, in Geographical Essays, Boston, 1909, pp. 690–724 (first published in *Proc. Amer. Acad. Arts and Sci.*, Vol. 31, 1896); reference on p. 701.

[11] N. M. Fenneman: Development of the Profile of Equilibrium of the Sub-aqueous Shore Terrace, *Journ. of Geol.*, Vol. 10, 1902, pp. 1–32; reference on p. 1.

[12] W. M. Davis: *ibid.*, p. 703.

[13] T. C. Chamberlin: Diastrophism and the Formative Processes: VI, Foreset Beds and Slope Deposits, *Journ. of Geol.*, Vol. 22, 1914, pp. 268–274; reference on p. 268.

It follows from the above argument that the absence of conspicuous salients and reëntrants developed as an adjustment to structure along the retrograded shore-line of a region of diversified structure is an indication of youth.

The changes in the features of fault coasts outlined in the foregoing paragraphs are those characteristic of their youth and adolescence. After the initial delay, to which reference has previously been made—a delay which may safely be assumed to be short—the stages of youth must, for reasons already stated, be passed through rapidly, and consequently we are much more likely to find fault coasts in the mature than in the young stage.

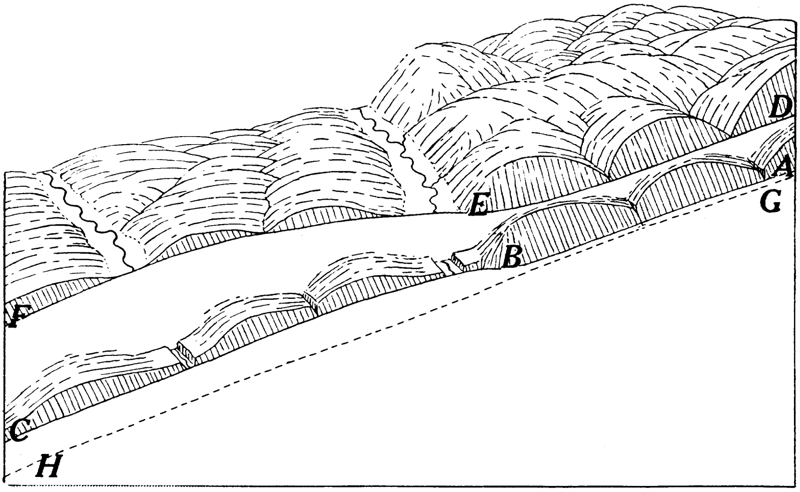

Fig. 7—Development of an embayment of the shore-line in an area of weak rocks. *AB*, resistant rocks; *BC*, weak rocks; *DEF*, form of the shore-line at a later stage; *GH*, line of the initial shore determined by a fault. In the pre-faulting cycle of subaërial erosion the weak rocks had been reduced to much lower relief than the resistant rock area.

Young fault coasts must, as we have seen, differ widely in many important respects from young coasts of other types; but when maturity is reached they must very closely resemble mature depressed coasts or uplifted coasts with contraposed shore-lines (Clapp; see footnote 17), the development of either of which may have occupied an immensely longer period.

Small development of salients and reëntrants as a result of adjustment to structure will still indicate probable fault origin early in the stage of maturity, and stream courses doubling back on themselves to reach the sea, if such have been developed, may be expected to persist. Otherwise proof of the fault origin of a mature coast may be impossible or may depend upon special, local features.

COMPLICATIONS

In the foregoing discussion it has been assumed that retrogradation of the shore-line goes on continuously; but it is possible that at some stage, perhaps quite early in the cycle, the waves become overloaded, owing perhaps to an increase in the amount of waste brought down by rivers, causing wave attack on the shore-line to become ineffective. In such a case adjustment of the form of the shore-line to the structure of the coastal land must cease, and progradation may occur. While the continental shelf will continue to grow in width the growth will take place entirely by addition of material at the outer edge.

INTERRUPTION OF THE CYCLE AFTER A PERIOD OF STILL-STAND FOLLOWING FAULTING

Interruption by Depression. Interruption of the first cycle by depression, after an appreciable amount of modification of the initial form has taken place, will give a new initial shore-line of the ordinary depressed type, which need not be further considered here.

Interruption by Uplift. Interruption by uplift taking place while the built platform of the interrupted cycle is still somewhat narrow, even though maturity may have been reached, will result in the exposure of a strip of sea floor as a narrow coastal plain with an appreciable seaward slope. Only this case will be considered (Fig. 8, blocks *B* and *C*).

The new initial shore-line (block *C*) will be simple, and the initial slope of the coastal plain will be such that the attack of the sea on the land will begin at once.

"The sea is able to begin the production of the submarine platform immediately off shore, shore-grade is quickly attained, youth and adolescence are of short duration, and the coast reaches a mature stage of development without the production of an off-shore bar."[14]

A recently published diagram (Fig. 9) of the western side of Osaka Bay, Japan, by Cushing,[15] which was received after this article was written, illustrates very well a sequential form developed from the stage represented in block *C* of Figure 8. A comparison of Figure 9 with block *C* of Figure 8, however, brings out certain differences. In the Osaka Bay example there appears to be no cut platform, indicating that deposition along the initial shore in the first cycle was even more rapid than has been assumed by the writer in the theoretical case, so that the effects of wave attack were still inappreciable when retrogradation was followed by progradation, evidence of which is seen in the fans which border the old land. The stratification of the coastal plain is represented in the diagram as parallel with the surface, but, in his description of the region, Cushing

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[14] F. P. Gulliver: *op. cit,*. p. 184.

[15] S. W. Cushing: Coastal Plains and Block Mountains in Japan, *Annals Assoc. Amer. Geogrs.*, Vol. 3, 1914, pp. 43-61.

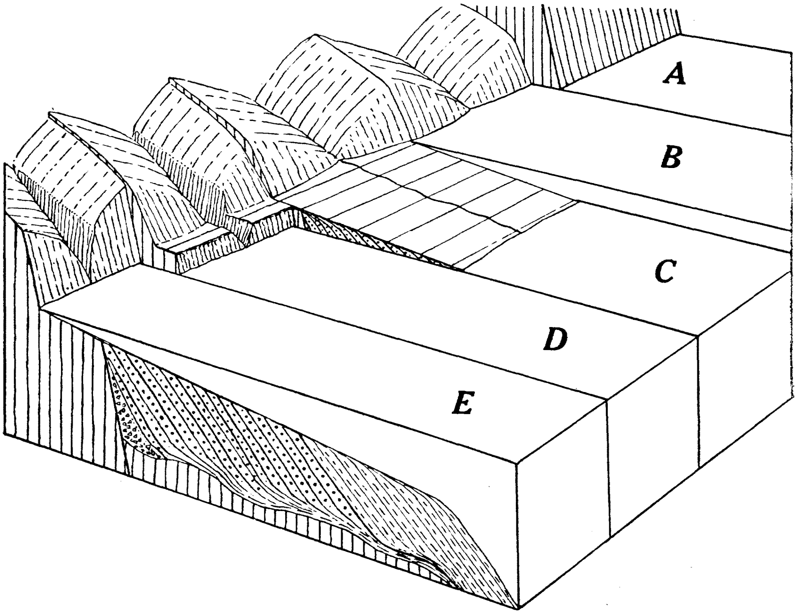

FIG. 8—A two-cycle fault coast. *A*, initial form of the first cycle; *B*, early maturity; *C*, the same, uplifted; *D* and *E*, sequential forms in the second cycle.

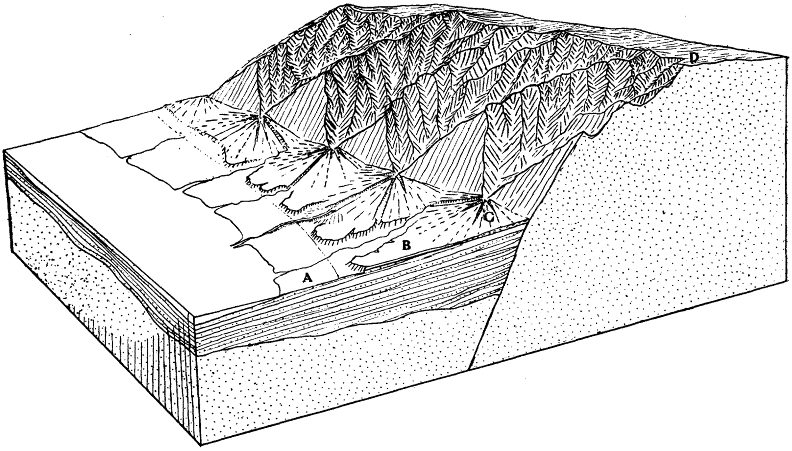

FIG. 9—Diagram of the western side of Osaka Bay, Japan. (After Cushing; reproduced with the author's permission.)

mentions updragging of the strata as proof of renewed uplift of the landward block.[16] The question presents itself whether the observed seaward dip may not be due in part to inclined deposition, that is to the initial dip of the foreset beds of the coastal plain.

Let us now return to our consideration of the theoretical case and to our assumption of uninterrupted retrogradation. The unconsolidated material of the outer part of the narrow coastal plain (Fig. 8, block *C*), the built platform of the first cycle, will be rapidly cut back, and the waves will soon beat upon the reëxposed fault scarp forming the seaward boundary of the cut platform. Professor W. M. Davis has suggested to the writer that a fault scarp thus reëxposed after burial by sediment might be termed ''resurrected''; and so the fault coast developed upon such a scarp in a second or later cycle may be termed a ''resurrected fault coast.'' It will be noted that such a coast has something in common with the contraposed shore-line type of Clapp.[17]

Redistribution of the waste derived from the destruction of the coastal plain will cause the built platform of the new cycle to grow rapidly seaward.

Rejuvenation of the topography of the coastal land will have begun very soon after uplift as a result of rapid trenching by extended rivers across the steeply sloping coastal plain. As the shore is cut back further rejuvenation will take place. On resistant rocks, however, the amount of stream work accomplished during rapid recession of the coast to the resurrected fault scarp may be slight.

After this stage, the rate of retrogradation on an older mass of resistant rocks will be very much slower, but the cut platform of the earlier cycle will eventually be destroyed. Block *D* of Figure 8 represents the coast when the uplifted cut platform has been partially destroyed, and block *E* a later stage when it has been completely cut away. The history of the now fully mature coast need not be followed further.

Successive uplifts will be followed by precisely similar consequences provided that matters are not complicated by elevation above or near to sea-level of the older mass of the seaward block.

Interruption of the first cycle by diverse movements, tilting, warping, etc., may occur, but the complications thus introduced need not be discussed here.

EXAMPLES OF FAULT COASTS IN NEW ZEALAND

THE MARLBOROUGH COAST

A Resurrected Fault Coast. The east coast of Marlborough (Fig. 10) from Cape Campbell southwestward to Kaikoura Peninsula may be described as a mature, resurrected fault coast with a projecting delta, built by a large river—the Clarence—in the first cycle, cut back somewhat after uplift, and added to in the present cycle, the modern portion of the delta passing northeastward into a continuous strand plain of very recent origin[18] (Figs. 12, 13, and 14). The rocks of the region are mainly weak mudstones, resistant, deformed limestone and older, resistant, deformed clastics,[19] each in turn forming the shore for a distance of several miles. Unfortunately, the physiographically very important boundaries between the mudstones and the limestones are not shown on the only detailed maps of the region, those of McKay.[20]

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[16] S. W. Cushing: *op. cit.*, p. 46.

[17] C. H. Clapp: Contraposed Shorelines, *Journ. of Geol.*, Vol. 21, 1913, pp. 537-540.

The mudstone areas are of moderate relief, having been reduced to mature forms and in some places completely planed down during periods of still-stand occurring between movements of uplift, the last of which took place so recently that, even on these weak rocks, small streams are not

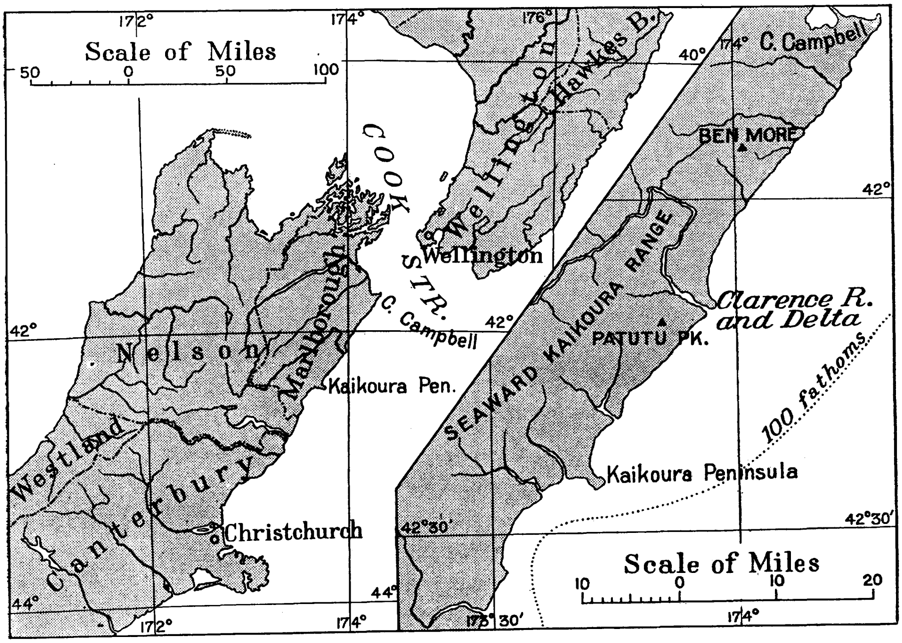

FIG. 10—Sketch-map of central New Zealand.

FIG. 11—Sketch-map of the east coast of Marlborough.

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[18] C. A. Cotton: Preliminary Note on the Uplifted East Coast of Marlborough, *Trans. N. Z. Inst.*, Vol. 46, 1914, pp. 286-294; reference on pp. 291-293.

[19] The mudstones referred to in the text are the predominant beds underlying and overlying the Amuri limestone in the area mapped by McKay (see footnotes 20 and 21) as "Cretaceo-Tertiary and Cretaceous;" the limestone referred to is the Amuri limestone of the same series; and the resistant, deformed clastics are the pre-Cretaceous rocks or older mass of the region. In addition to the rocks mentioned a very resistant conglomerate, the Great Marlborough conglomerate (J. A. Thomson: Report of Palaeontologist, *Geol. Surv. of N. Z., 7th Ann. Rept.*, 1913, pp. 121, 123-134; C. A. Cotton: On the Relations of the Great Marlborough Conglomerate, etc., *Journ. of Geol.*, Vol. 22, 1914, pp. 346-363), reaches the shore at several places with mudstone on either side.

[20] A. McKay: On the Geology of the East Part of Marlborough, *Geol. Surv. of N. Z., Rept. Geol. Expl. dur. 1885*, pp. 27-136, 1886; map opp. p. 42.

A. McKay: On the Geology of Marlborough and South-east Nelson, *Geol. Surv. of N. Z., Rept. Geol. Expl. dur. 1888-89*, pp. 85-185, 1890; map opp. p. 96.

yet graded with respect to present base level and larger streams still occupy narrow-floored, precipitous-sided valleys.[21] The measure of the relief rarely exceeds 600 or 700 feet.

On the resistant rocks, both the limestone and the older-mass clastics, the relief is strong, a limestone peak, Ben More, four miles from the sea reaching a height of 4,081 feet, and the older-mass rocks southwestward of the Clarence mouth rising to 2,190 feet one mile inland, to 3,820 feet in Patutu Peak two miles inland, and to much greater heights in the Seaward Kaikoura Range at an increasing distance from the sea. (Fig. 15 is a profile of the coast at this point, drawn to the same horizontal and vertical scale.) On other parts of the coast the relief on these rocks is somewhat less strong, but they nowhere present subdued forms. In these rocks the rivers, with the exception of the largest, are not graded, and dissection with respect to present base level is still in a very young stage.

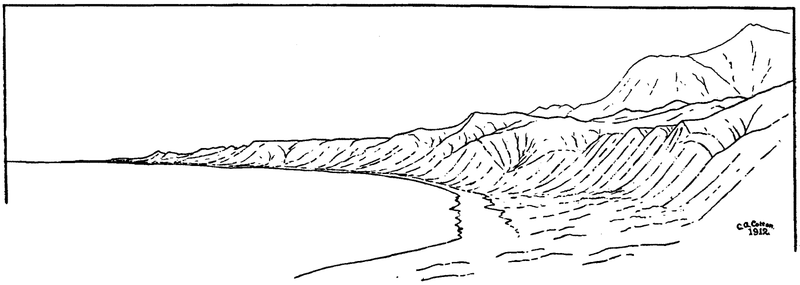

FIG. 12 – View of the Marlborough coast, looking southward. The cliffs of the mature coast appear on the right, the strand plain in the foreground, and the projecting delta on the left.

The continuous cliffs of the coast, though bordered now by a strand plain, are remarkably well preserved even where composed of mudstone, thus showing that, quite recently, the shore-line was receding at all points.

The line of these cliffs has the simple curves of a mature coast, but it exhibits a remarkable indifference to structure, explicable only on the hypothesis of rapid development from an initial faulted form outlined on an earlier page, and quite inexplicable on the only alternative hypothesis, that of development to maturity by an enormous amount of cliff-recession from some other initial form of coast. A mature coast developed in the latter way on rock formations so strongly contrasted as those of Marlborough would show pronounced salients on the areas of resistant rocks, separated by bays where the weak mudstones reach the sea, on account both of the small resistance of the latter to wave attack and of their low relief. It seems probable that the width of the combined cut and built platforms would, in the latter case, also be much greater than that of the continental shelf[22] of the Marlborough coast. This is, however, debatable since the proportion of the total width occupied by the cut platform is a matter of inference; but reasons will be given in the next section for the belief that the cut platform is relatively narrow.

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[21] C. A. Cotton: *op. cit.* sub 18.

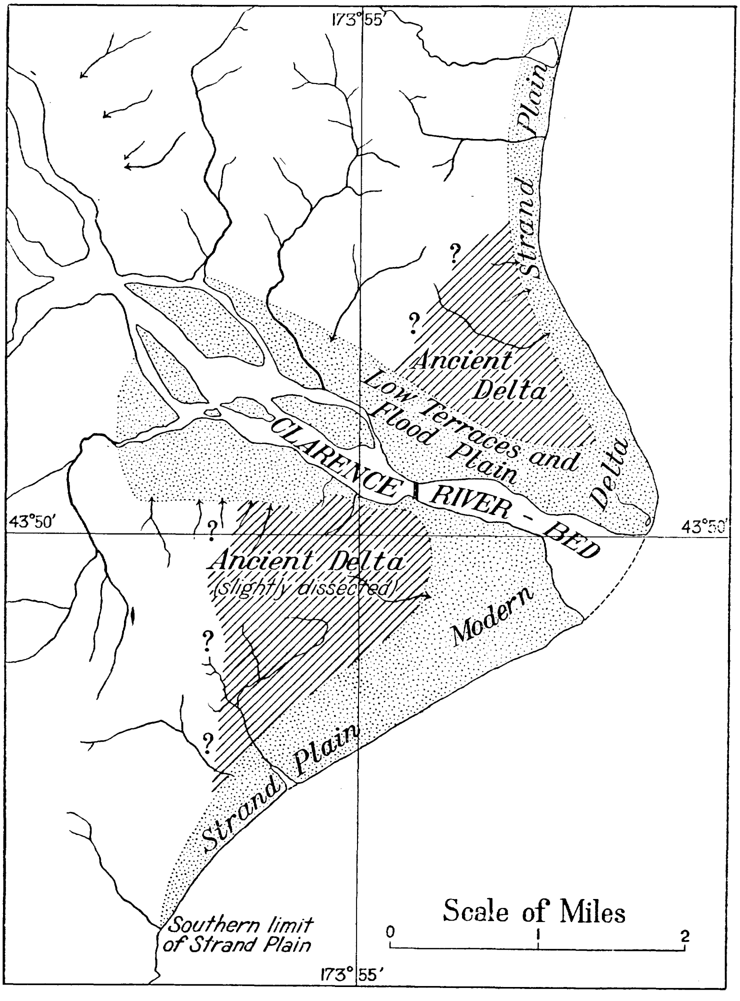

FIG. 13—Physiographic sketch-map of the Clarence delta.

Along this coast there is a general absence of islands, indicating that the depth to which the seaward block subsided along the initial fault was considerable; but at the southwestern end there is one large, land-tied island, Kaikoura Peninsula. This "island" certainly does not owe its position as the only prominent salient on the coast to any great power of resistance to wave attack possessed by its rocks, for it is composed of weaker materials than the adjacent mainland. The initial island was probably the unsubmerged portion of an unevenly depressed seaward block. Its flat top and terraces at lower levels indicate that it has been completely planed off once by marine erosion and partially planed during several later periods of still-stand separating episodes of uplift. The "island" is now tied to the mainland by the confluent deltas of several streams forming the Kaikoura Plain, where locally the shore-line has advanced seaward owing to a very abundant supply of waste from the Seaward Kaikoura Range.

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[22] It appears to the writer desirable to use the well-established term "continental shelf" for this feature even when it fringes an island. The use of the adjective "continental" is unfortunate, but the use of a second term "island shelf" for what is genetically the same feature does not afford a satisfactory way out of the difficulty.

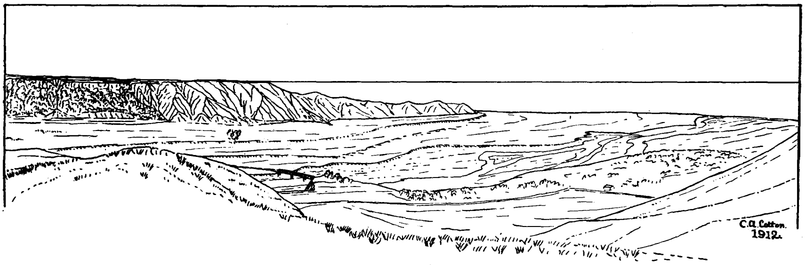

FIG. 14—View looking seaward from the surface of the uplifted Clarence delta, showing part of the uplifted delta on the left, low terraces and flood-plain of the Clarence River in the center, and the modern delta on the right.

Bordering this mature coast there is, as required by the hypothesis, a continental shelf or submarine platform (see Figs. 11 and 15), the outer edge of which is about twelve miles from the shore and at a depth of about seventy fathoms. Though not very numerous soundings have been recorded, the Admiralty chart (New Zealand, Sheet 8) shows a sufficient number to make it apparent that the platform slopes evenly and that the underwater profile is graded.

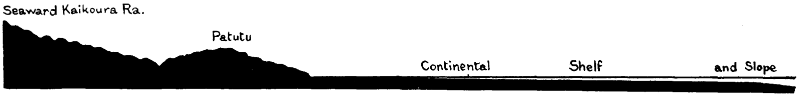

FIG. 15—Profile of the coast southward of the Clarence River. (The profile of the continental slope is hypothetical, as the available soundings indicate merely deep water, not definite depths, beyond the edge of the shelf, which is situated at a depth of about 70 fathoms.)

The Fault Line Must Be Situated Close to the Present Shore-Line. For reasons which follow, the writer considers it highly improbable that the shore-line can have receded more than a very short distance from the fault line. The evidence in favor of this view also seems to afford proof of the correctness of the application of the fault hypothesis to this coast.

It is important to recall that the average relief of the land immediately behind the present shore-line is very strong; also that the dissecting valleys of the present cycle are quite immature even on the weakest rocks, indicating an extremely youthful stage of dissection in the present cycle; and finally that there is an absence of notable salients and reëntrants in the shore-line itself. In view of these facts it seems impossible that the coast can have been cut back far from the fault line since the last uplift. If, for example, even a mile or two of recession had taken place on a coast composed in part of very resistant and in part of very weak rocks, with a straight shore-line transecting all structures indifferently as the mature result, the rate of recession of the coast on the very weak rocks must have been enormously retarded to allow recession on the neighboring mountainous areas of very resistant rocks to keep pace with it. Under such conditions the areas of weak rocks would, at the same time, have been reduced by subaërial agencies to lowlands of small relief with all valleys widely opened and all streams graded with respect to present sea-level as base level; whereas, as pointed out above, the dissection even on these areas of weak rocks is characterized by extreme youth of the erosion features. Only a small fraction of the twelve-mile-wide submarine platform can, therefore, be regarded as cut landward from the fault. The remaining larger fraction must be an apron of waste built out upon the submerged block. This is not surprising when the large quantity of waste constantly being poured into the sea by the torrential stream of this mountainous region is taken into account. The supply of waste from this source is undoubtedly far in excess of that resulting from wave action along the shore, and so it is only to be expected that the waste apron will greatly exceed in width that portion of the platform cut upon the basement rocks of the landward block.

The waste-apron portion of the submarine platform will really consist of two distinct portions, the outer a true built platform, an entirely constructional feature built outwards since the present position of sea-level was assumed, and the inner a part of the cut platform, which has been cut, however, upon the waste apron (or aprons) built forward when the whole region stood lower and when the sea was attacking the coast at higher levels. (In Figure 8 the theoretical structure of such a platform, developed in two cycles, is shown in section on the side of block *E*. The sediment of the current cycle is indicated by lighter lines than that of the earlier cycle.)

The Coast Is Not a One-Cycle Fault Coast. Reasons must now be given for describing the Marlborough coast as a mature, resurrected fault coast as distinguished from a mature, one-cycle fault coast. As indicated in Figure 8, block *D*, a resurrected fault coast is characterized in its early mature stage by the presence of an uplifted cut platform or remnants of one. At a later stage, however, these will disappear (block *E*); and the narrower the cut platform of the earlier cycle the shorter-lived it will be in the later cycle. A few narrow remnants of uplifted marine cut platforms are present in Marlborough, but they are not as a rule conspicuous features. Their general absence, in view of the small amount of recession of the coast landward from the fault which, it seems, can possibly have taken place in the present cycle, must indicate that at no period since the initiation of the coast fault has recession proceeded far landward.

In addition to the remnants of uplifted cut platforms the Marlborough coastal region presents evidence of extremely recent, strong uplift, chiefly in the form of (a) rejuvenated topography well developed on the areas of weak rocks but only incipient on the areas of resistant rocks; and (b) the presence at the mouth of the Clarence River of the delta previously referred to, which is as yet but little dissected though uplifted 500 feet.[23]

This delta of the Clarence was built out from a shore the line of which practically coincided with that of the present coast, and that shore appears to have been a young, one-cycle fault coast the scarp of which descended into deep water, for the massive conglomerate of which the foreset portion of the delta is composed may be traced to sea-level, 500 feet below former sea-level, at a distance of about a mile from the former shore, and it extends to an unknown greater depth. The presence of this delta, therefore, proves that the uplift of which there is evidence took place later than the formation of the initial scarp; that is to say, it proves that the coast is of the ''resurrected'' type.

The Post-Faulting Uplift Regional, Not Differential. There remains to be considered an alternative hypothesis that suggests itself in explanation of the development of the present coast from the fault coast of the first cycle (that in which the 500-ft. delta was built). To this may be given the explanatory name ''hypothesis of renewed faulting,'' thus distinguishing it from the ''hypothesis of regional uplift following faulting'' upon which the preceding arguments are based.

Obviously renewed faulting with uplift of the landward block only, and the formation of a new initial fault coast, is a possibility that must be taken into account. The hypothesis has, indeed, the advantage of dispensing with the necessity of explaining the destruction of a coastal plain after uplift. In the concrete case under discussion, however, the hypothesis fails to explain the uplift of the Clarence delta; for the delta was, as shown in the last section, built out upon the seaward block. Clearly, therefore, in the case of the Marlborough coast, post-faulting uplifts have affected the seaward as well as the landward block; in other words, they have been regional and of the same character as those postulated in the theoretical study of resurrected fault coasts on an earlier page.

The diagrams in Figure 16 represent stages in the growth of a composite (i. e., two-cycle or multi-cycle) delta, which, like that of the Clarence, has been built by a vigorous river in front of a fault coast where wave action has usually been powerful, sometimes succeeding in cutting back the shore even at the river mouth in the face of an abundant supply of waste, though sometimes there has been an excess of waste leading to active delta-building and progradation of the shore. In the figure, *A* represents the initial stage, and it is assumed that a preëxisting valley of the river has been transected by the scarp of the initial coast. *B* represents

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[23] C. A. Cotton: *op. cit.* sub 18.

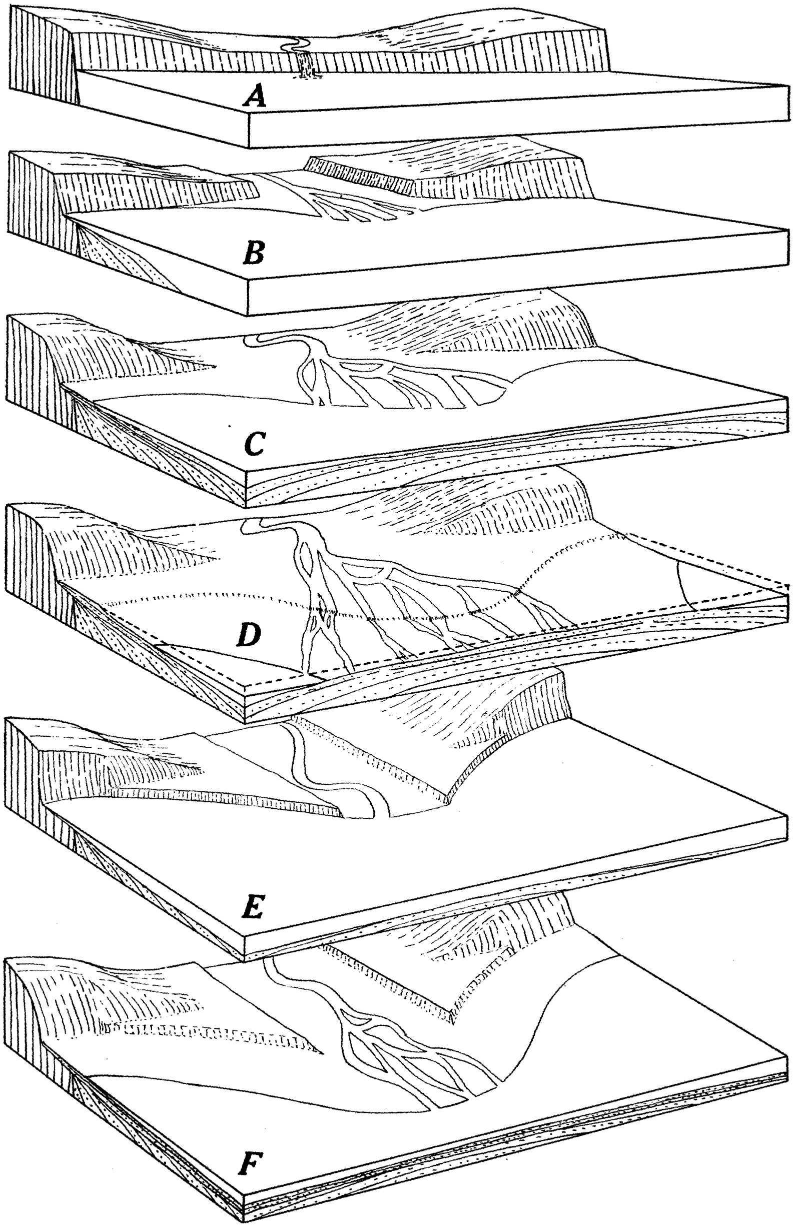

FIG. 16—Diagrams of stages in the growth of a composite delta with a history similar to that of the Clarence delta.

a stage when the shore has been cut back somewhat and a submarine platform has taken form, allowing the growth of a delta to begin. At stage *C* the submarine platform and delta have grown considerably. *D* represents the same stage as *C* after uplift has taken place, the form represented being now the initial form of a new cycle. At stage *E* the attack of the waves has triumphed for a time, as has certainly been the case at a corresponding stage in the history of the Clarence delta, so that the front of the uplifted delta has been cut away. *F* represents a stage of renewed delta-building and progradation of the adjacent coast corresponding to the present state of the coast in the neighborhood of the Clarence River.

EXAMPLES NEAR WELLINGTON

The coasts of the southwestern extremity of the North Island of New Zealand, both that facing southward and that facing northwestward, are regarded by the writer as sequential forms of fault coasts. In an earlier paper, in which these coasts have been described,[24] evidence of uplift has been put forward, and so the coasts may be provisionally termed resurrected fault coasts; but it remains uncertain whether the uplift has been regional or has been by renewed faulting. There is in this case no uplifted delta, nor has any portion of the platform built beyond the line of the initial coast, if uplifted, escaped destruction to bear witness that the seaward region has shared in the uplift of the land.

While evidence of uplift of the land is to be found in both the eastern and western portions of the area included in Figure 17, there is a central area of subsidence, the area occupied by Port Nicholson and a small adjacent land area with an obviously drowned shore-line, and on the northwestern coast there is an area of less extensive subsidence including the drowned valleys forming Porirua Harbor. It is uncertain whether the movements resulting in the production of these sunken areas were or were not in part contemporaneous with the rise of the adjacent areas, but they seem to have been mainly later.

The uplift of over 200 feet in the eastern and western portions of the Wellington district, which initiated the latest of a succession of brief cycles of both subaërial and marine erosion (the latter slightly disturbed by a further small movement within historic times), must have taken place very much earlier than the latest significant movement in the Marlborough coastal region. This is indicated by the fact that valleys in the Wellington area have been well opened out in this cycle though they are excavated in resistant rocks. In view of this fact it is at first sight rather surprising that considerably larger areas of uplifted cut platforms are preserved, corresponding to stage *D* of Figure 8; but the explanation appears to be that the duration of some at least of the earlier cycles (subsequent to the formation of the initial fault) was also longer here than in Marlborough. Platform remnants on the southern coast are shown in Figures 18 and 19. In Figure 18 remnants of two platforms and in Figure 19 remnants of three are seen one above another.

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[24] C. A. Cotton: *op. cit.* sub 18.

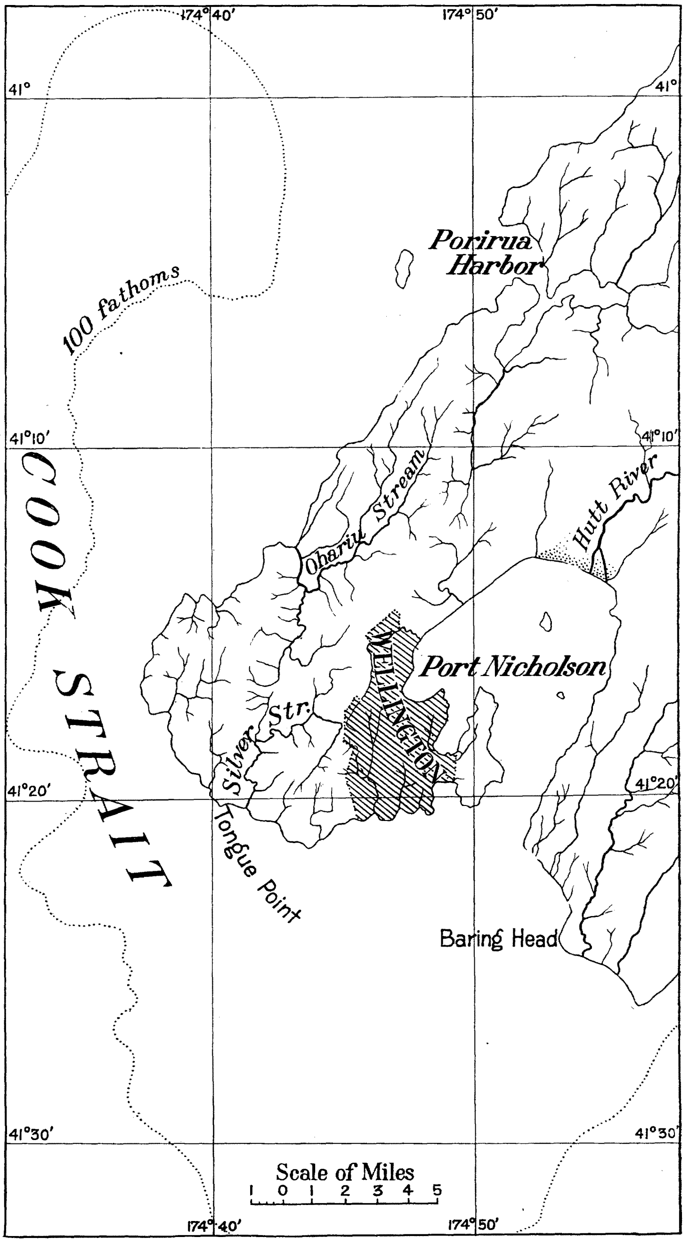

FIG. 17—Sketch-map of the coasts in the vicinity of Wellington.

The features of the shore-line are of a similar nature to those which will be found in the case of a contraposed shore-line;[25] but the writer considers the explanation based on the fault-coast hypothesis probably correct because of the presence here of streams rising near the coast and making long excursions inland before eventually reaching the sea, a type of stream course which was shown, on an earlier page of this paper, to be likely to occur on a fault coast. Among the most conspicuous of such courses are those of the Ohariu and the Silver Stream (Fig. 17).

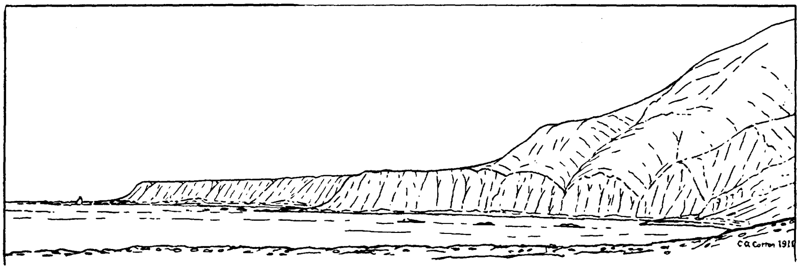

FIG. 18—Two remnants of cut platforms, each with a thin covering of gravel, at Tongue Point, Wellington. The lower and broader platform is at a height, at the rear, of 240 ft., and the upper remnant, of 450 ft.

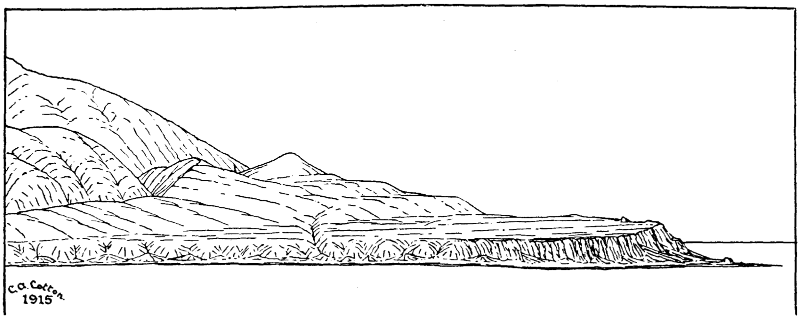

FIG. 19—Platform remnants at Baring Head, Wellington.

The narrowness of the continental shelf does not in this case indicate youth, for its growth is interfered with by the strong tidal currents of Cook Strait. The irregularity of the edge of the shelf as defined by the one-hundred-fathom line (Fig. 17) is, no doubt, due largely to the same cause. A pronounced salient of the shelf opposite the subsided Port Nicholson area, where a reëntrant of tectonic origin might be looked for, emphasizes the fact that the shelf is largely a built feature. This salient is difficult to explain, for, though the Hutt River here supplies a large and continuous stream of waste, most of this is trapped in the Port Nicholson depression, which has not yet been filled. Possibly the shelf broadens normally with increasing distance from tide-swept Cook Strait, but has been cut off southeastward by recent subsidence which has probably taken place beyond the area with which we are at present concerned.

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[25] C. H. Clapp: *op. cit.* sub 17.

ONE-CYCLE FAULT COASTS

A Miniature Example at Wellington. A miniature example of a one-cycle fault coast is provided by that portion of a young fault scarp at Wellington which forms the northwestern shore of Port Nicholson (Fig. 17). The fault scarp was first described by Bell[26] and later by the writer.[27]

The scarp trends southwest and northeast and runs inland in both directions, its northeastern continuation extending far up the valley of the Hutt River. The fault cuts a sub-mature surface with a somewhat steep general slope towards Port Nicholson, the proximal portions of transected spurs alternating with streams the largest of which are mature at their mouths. The initial scarp facing the sea must have presented the appearance of a sharply cut section, the trace of which in plan would be a simple line. At sea-level this line would be broken only by slight embayments at the mouths of three of the larger streams the valleys of which were slightly drowned by a small movement of depression on the landward or upthrow side of the fault. The height of the scarp above sea-level would vary according as it cut across spurs or ravines, and it would, therefore, present the appearance of a line of facets. The slope of the scarp would be probably less steep than the hade of the fault, for, if the latter were steep, material would slide away from the growing scarp until a slope of equilibrium was reached. All the smaller streams would cascade from the mouths of hanging valleys. Deep water would extend close in to the base of the scarp unless a very large amount of talus had accumulated during faulting. In any case there would be no wave-cut platforms at the base, such as would be present if the line of cliffs had been cut by marine erosion.

These characteristics are still recognizable, though they have been somewhat modified in the post-faulting period. Two types of post-faulting modifications can be recognized—subaërial and marine. As subaërial modifications we find, throughout the length of the scarp, notches that have been cut by revived streams in the bottoms of pre-faulting ravines; but the smaller of these are still hanging. At the southwestern end of the scarp, where it runs inland, the edges of the initial facets are rounded off, mainly, no doubt, by soil creep. As a result of modification by marine erosion there are now, along the shore of Port Nicholson, sharp-edged facets which are not, strictly speaking, remnants of the fault scarp, but are wave-cut cliffs worn back a little from the fault line. Narrow rock platforms are present at the base of these cliffs. Small deltas have filled the drowned mouths of the larger streams and now project slightly beyond the general line of the shore, while the Hutt River, entering Port Nicholson from the northeast, has built a larger delta part of the way along the scarp.

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[26] J. M. Bell: The Physiography of Wellington Harbour, *Trans. N. Z. Inst.*, Vol. 42, 1910, pp. 534-540.

[27] C. A. Cotton: Notes on Wellington Physiography, *Trans. N. Z. Inst.*, Vol. 44, 1912, pp. 245-265; reference on p. 257.

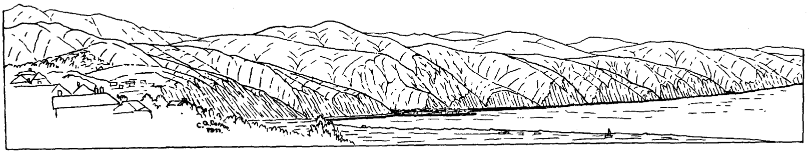

FIG. 20—The one-cycle fault coast formed by the Wellington fault scarp.

The Coast of Southern Marlborough. A short stretch of coast that is perhaps a young, one-cycle fault coast is to be found in southern Marlborough, extending a short distance southwestward from Kaikoura Peninsula (Fig. 11).

The most remarkable feature of this coast is the narrowness, or absence, of the continental shelf. A depth of 200 fathoms "and no bottom" is recorded on the Admiralty chart (New Zealand, Sheet 8) at a distance of about two miles from the land, and a great depth of water is vouched for by local fishermen. This suggests recent subsidence along a fault line close to the present shore; and the land presents the appearance of a fault scarp (Fig. 21), as though a strip had recently subsided along an arcuate line a little within that of the initial scarp of the resurrected fault coast to the northeast that has been already described. A very similar result might, however, have been produced by off-shore subsidence as a result of renewed movement on the original fault (if we may assume that the fault coast now recognized to the northeast formerly extended along this portion of the coast also). Such off-shore subsidence would in most cases be followed by increased activity of wave action on the shore, producing a cliffed shore-line not unlike that of a young fault coast. Further study in the field is necessary before a more definite statement as to the nature of this strip of coast can be made.

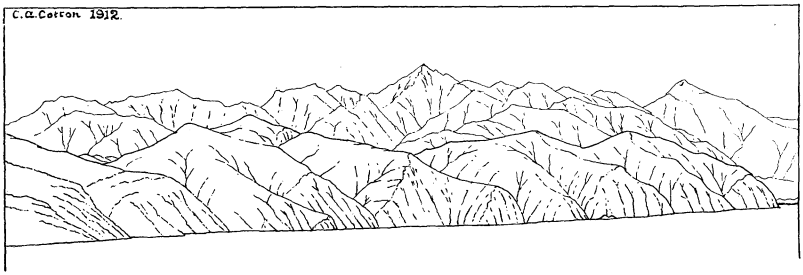
C.A.Cotton 1912.

FIG. 21—The Marlborough coast southwestward of Kaikoura Peninsula.

The Thames Fault Coast. This article would be incomplete without a brief reference to the western coast of the Hauraki, Coromandel, or Cape Colville Peninsula in the North Island of New Zealand (Fig. 22), where, in the neighborhood of the mining town of Thames, the presence of a fault coinciding with the shore-line and hading seaward at an angle of 45° has long been known from mining operations. It is known locally as the "beach slide." A long and imposing fault scarp which is the superficial development of the beach slide and associated parallel faults was first recognized as such by Lindgren,[28] and the southern portion of it has recently been described by Henderson,[29] who has also summarized the observations of a number of other authors on the subject.[30]

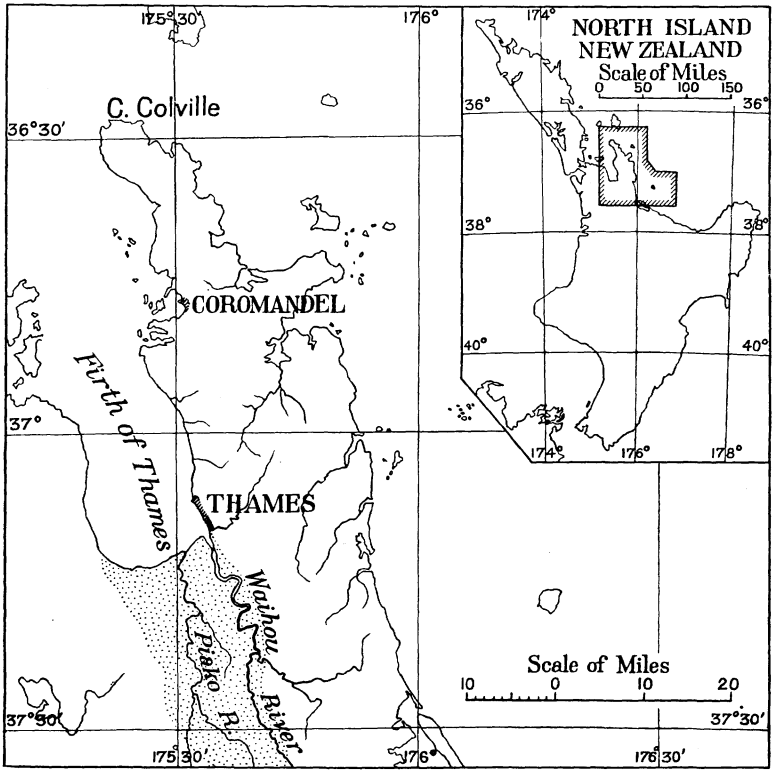

FIG. 22—Sketch-map of the Hauraki Peninsula. The inset map of the North Island of New Zealand indicates the locality.

The shore-line of the fault coast may, by its simplicity on the map (Fig. 22), be recognized, extending about twenty miles northward of Thames. It extends also many miles to the south, separating a maturely dissected, mountainous region, composed mainly of volcanic rocks, on the east, from a down-thrown area, invaded by the sea, on the west. A great part of this area has been reclaimed from the sea by the rapidly growing, confluent deltas of the Waihou and Piako Rivers and their tributaries. (This area is stippled in Fig. 22.) The unfilled, northern portion of the depressed area is known as the Firth of Thames.

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[28] W. Lindgren: The Hauraki Goldfield, New Zealand, *Eng. and Min. Journ.*, Feb., 1905, p. 261.

[29] J. Henderson: The Geology of the Aroha Subdivision, *N. Z. Geol. Surv. Bull. 16*, 1913.

[30] *Ibid*, pp. 49-51.

Notable recession of the shore-line from the fault at Thames has not taken place, mainly, no doubt, on account of the feebleness of wave action in the landlocked Firth of Thames, and partly on account of the rapidity of sedimentation, though the initial depth of water close to the shore must have been very great, as a bore-hole has been put down to a depth of over 1,100 feet through silt without reaching solid rock.[31]

Northward beyond the fault coast and on the whole eastern seaboard there is a young depressed coast. The latest movement, therefore, of importance in determining the outlines of the Hauraki Peninsula appears to have been a tilt to the north and northeast of a surface of strong relief, maturely dissected in a single cycle, the Thames fault coast forming the western boundary of the tilted area and separating it from the adjacent deeply submerged block. A comparison of Figure 22 with Figure 3 shows that the western coast of the Hauraki Peninsula, as a whole, affords an example of a transition from a fault coast to a depressed coast.

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[31] C. Fraser: The Geology of the Thames Subdivision, *N. Z. Geol. Surv. Bull. 10*, 1910, p. 32.